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An Assessment of ELINT Exploitation for Situational Awareness Visualisations on Operator Situational Awareness

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ABSTRACT

An Interactive Project Agreement (IPA) between Electronic Warfare and Radar Division of the Defence Science Technology Organisation and Thales Australia (formerly ADI Limited) has an initial aim to evaluate DSTO innovations flowing from its ELINT Exploitation for Situational Awareness (ELEXSA) task within Thales Australia's operational situational awareness tool Llama-Cheetah. This document outlines the human in the loop experiment undertaken to determine whether the visual enhancements provided by ELEXSA computational components increased operator situational awareness, thereby improving their ability to achieve tactical goals. Analysis of three hypotheses showed that ELEXSA Enhanced Llama: (1) increases operator survivability; (2) shortens mission duration; and (3) reduces the time helicopter spends vulnerable to detection, compared to Standard Llama. Analysis of anecdotal reports showed that operators using ELEXSA Enhanced Llama had lower workload and stress levels and more accurate perceptions of their vulnerability to radar detection than operators using Standard Llama.

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EXECUTIVE SUMMARY

An Interactive Project Agreement (IPA) between Electronic Warfare and Radar Division (EWRD) of the Defence Science Technology Organisation (DSTO) and Thales Australia (formerly ADI Limited) was agreed in September 2004. An initial aim of the agreement is to evaluate DSTO innovations flowing from its ELINT Exploitation for Situational Awareness (ELEXSA) task within Thales Australia's operational situational awareness tool Llama-Cheetah.

As Llama-Cheetah is a situational awareness tool hosted in the Joint Command Support Environment, demonstrations employing Llama-Cheetah have a technological fidelity matching existing operational capabilities. Under the IPA, Thales Australia developed two versions of Llama-Cheetah: Standard Llama and ELEXSA Enhanced Llama which incorporated some of the ELEXSA computational components.

In order to assess the effect of the ELEXSA visualizations on operator situational awareness, a human in the loop experiment was undertaken that compared the performance of one group of operators using ELEXSA Enhanced Llama against the performance of another group of operators using Standard Llama. Both groups of operators were tasked with achieving the same tactical goals in the same operational scenario.

The experiment was conducted using a simulated tactical environment. Each operator was required to navigate a helicopter through a hostile littoral environment containing enemy radars integrated with Man-Portable Air Defence System (MANPADS) and then to land the helicopter on a host ship. The experiment recorded the times associated with the execution of the helicopter's mission, including times when the helicopter was within the detection range of the enemy radars, and the time of landing on the host vessel. The experiment also recorded any failure to reach the host ship due to either being shot down by a MANPADS or running out of fuel. Measurements were analysed to determine whether the ELEXSA enhancements improved, degraded or had no impact on the operator's awareness of threats in the tactical environment. The

analysis consisted of three statistical hypothesis tests and interpretation of anecdotal reports of the operator's experience.

Analysis of the three hypotheses, at 95% confidence level, showed that ELEXSA Enhanced Llama: (1) increases operator survivability; (2) shortens mission duration; and (3) reduces the time helicopter spends vulnerable to detection, compared to Standard Llama.

Analysis of interview results showed that operators using ELEXSA Enhanced Llama had lower workload and stress levels and more accurate perceptions of their vulnerability to radar detection than operators using Standard Llama.

Authors

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Dr Keith Mason is a Senior Research Scientist with 20 years experience in DSTO. He has a Ph.D. in Computer Science from the University of Adelaide (1984) and also a Postgraduate Diploma in Management from APESMA/Deakin University (1995) and is currently a participant in the Graduate Program in Scientific Leadership (University of Melbourne). His recent work has focused on developing, demonstrating and evaluating techniques for signal exploitation and decision aids supporting situational awareness using data from distributed electronic warfare sensors.

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Jeffrey Sturm is a Senior Technical Manager and has over twenty five years engineering experience in the Defence industry. He has a Bachelor of Science (Applied Mathematics) from La Trobe University (1978), Bachelor of Engineering (Electrical) from Chisholm Institute of Technology (1983), Graduate Certificate of Information Technology (Software Engineering) from Queensland University of Technology (1999), Graduate Certificate of Information Technology (Enterprise Wide Systems) from Queensland University of Technology (2001) and a Master Of Information Technology from Queensland University of Technology (2003). He has a detailed knowledge of project and technical management, complete life-cycle of large software intensive systems and real-time system development. His recent work has focussed on research and development in the areas of Electronic Warfare, Unmanned Aerial Vehicles and Open Architectures.

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Craig Keogh is a Software Engineer and has over five years engineering experience in the Defence industry. He has been awarded a Bachelor of Computer Science from Adelaide University (2000). He has detailed knowledge of software engineering environments, software integration and testing, and simulation and modelling using the High Level Architecture (HLA) framework. His recent work has been focused on research and development in the areas of Electronic Warfare and Open Architectures.

Catherine Howard
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Catherine Howard is a Professional Officer with 10 years experience in DSTO. She has a BSc (1992) degree from University of Queensland, an Honours (1993) from the University of Tasmania and a Graduate Diploma in Computer and Information Science (2002) from the University of South Australia. She has worked in a variety of areas including passive missile warning systems, RF propagation in maritime environments, modelling and simulation, the virtual surface ship. Her recent work has focussed on the exploitation of Electronic Intelligence data. She has recently commenced a PhD in the use of automated reasoning techniques to provide dynamic decision support to tactical military commanders.

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1. Introduction

An Interactive Project Agreement (IPA) between Electronic Warfare and Radar Division (EWRD) of the Defence Science Technology Organisation (DSTO) and Thales Australia (formerly ADI Limited) was agreed in September 2004. An initial aim of the agreement is to evaluate DSTO innovations flowing from its ELINT[1] Exploitation for Situational Awareness (ELEXSA) task within Thales Australia's operational situational awareness tool Llama-Cheetah.

As Llama-Cheetah is a situational awareness tool hosted in the Joint Command Support Environment, demonstrations employing Llama-Cheetah have a technological fidelity matching existing operational capabilities. Under the IPA, Thales Australia developed two versions of Llama-Cheetah: Standard Llama and ELEXSA Enhanced Llama which incorporated some of the ELEXSA computational components.

In order to assess the effect of the ELEXSA visualizations on operator situational awareness, a human in the loop experiment was undertaken that compared the performance of one group of operators using ELEXSA Enhanced Llama against the performance of another group of operators using Standard Llama. Both groups of operators were tasked with achieving the same tactical goals in the same operational scenario.

The experiment was undertaken between November 2005 and February 2006 and the results are reported in this document.

2. ELEXSA

One driver for DSTO's ELEXSA task is a need to improve the survivability of ADF units such as troop transport vessels which do not have Electronic Warfare (EW) threat warning systems or EW skilled operators but still need timely and accurate information about potential threats in their tactical environment in order to stay in safe locations.

Under the ELEXSA task, EWRD has developed knowledge intensive algorithms to visualise the detection capabilities of threat radars in a manner which can be easily understood by operators without specialist EW expertise. These algorithms enrich ELINT data with additional information such as technical intelligence in order to compute detection ranges of threat systems against specific vessels or aircraft.

[1] ELINT Electronic Intelligence

This knowledge intensive process comprises two stages known as Object Assessment (OA) and Situation Assessment (SA). OA is a sequential information enrichment process whereby a signal level representation of a sensed entity is transformed through emitter and platform representations into a capability representation. The process of information enrichment is shown in Figure 1.

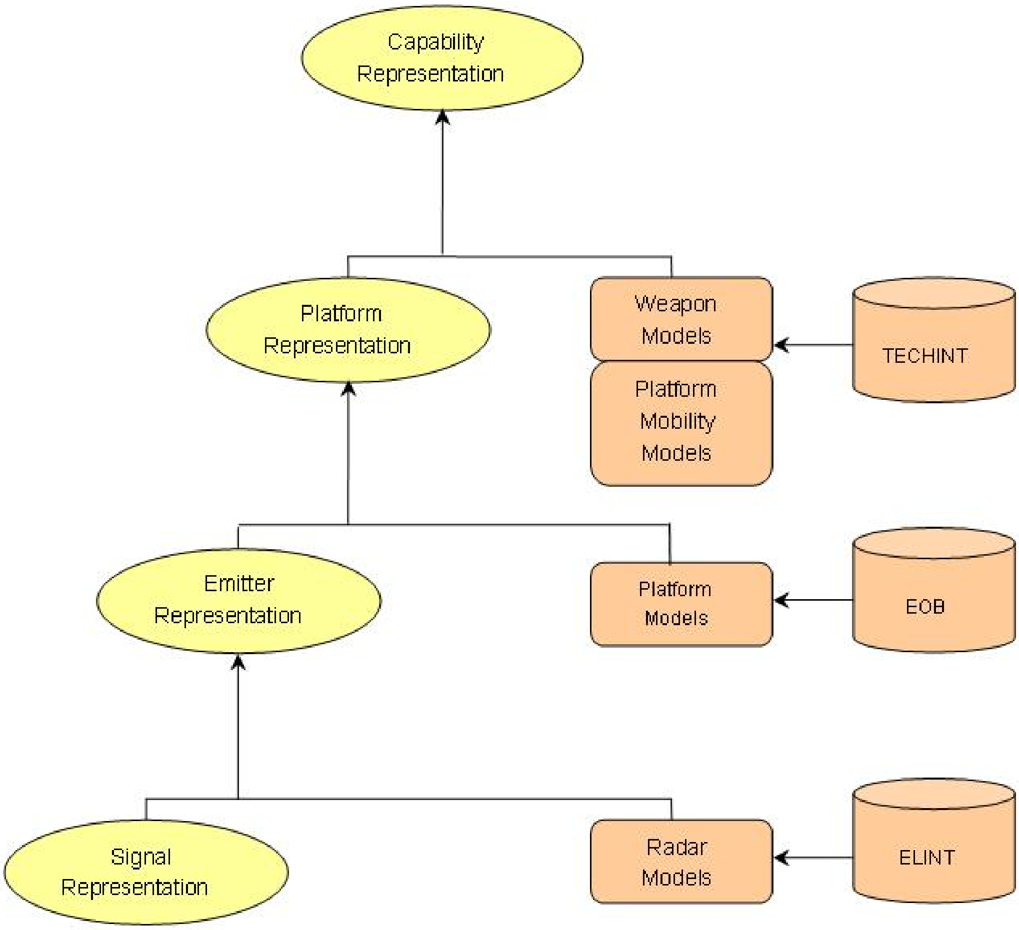

Figure 1. ELEXSA's Process of Sequential Enrichment.

The aim of SA is to compute relationships of interest between sensed entities, such as the detection range of a radar against a specific aircraft. ELEXSA SA uses attributes derived in ELEXSA OA (such as radar cross section and radiated power) and domain knowledge (such as propagation physics) to compute detection ranges. Figure 2 shows a visualisation of ELEXSA SA.

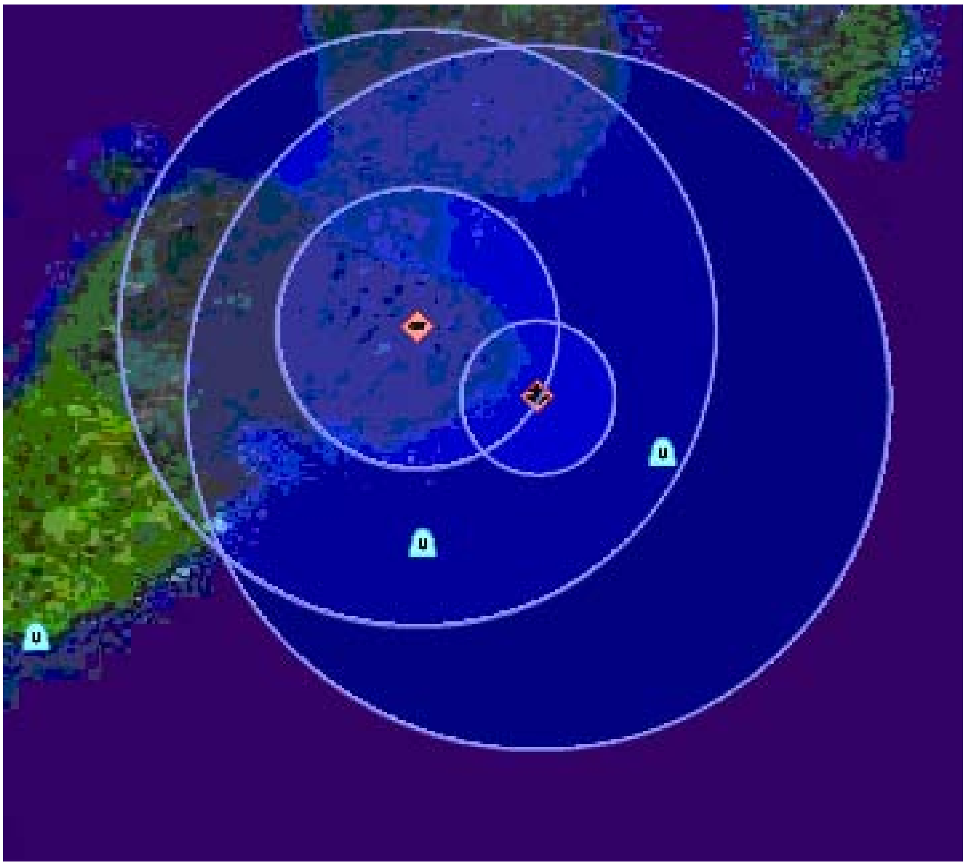

Figure 2. Sample ELEXSA Visualisation.

3. Llama

The Joint Command Support System (JCSS) supports the staff in operational or strategic headquarters. It enables commanders to manage and communicate the complex information required to plan and execute joint force operations and exercises. The JCSS communicates with other Command Support Systems as well as civil and other Government authorities through Defence and public network communications facilities.

Llama is a situation monitoring tool within the JCSS environment. Llama provides the Joint Forces with the ability to manipulate and view situational data on a geographic display, as well as to manage large amounts of information relating to the positions and movements of entities in any selected area of interest. An extendable suite of planning and command decision aids is available within Llama to support analysis, monitoring and planning. Llama supports a networked environment. A Llama Internet

Server manages the picture, map, scene, overlay and template libraries. Connecting Llama clients are able to use a set of common libraries.

The track data displayed in Llama is managed by Cheetah. Cheetah is a server application that can communicate with other Cheetah servers and other command support systems. Cheetah servers can be connected together using standard PC networking (TCP), email (SMTP) or serial links in star, web or serial network topologies. Cheetah servers perform track correlation, fusion, purging and persistent storage. External sources can pass track data to Cheetah in a number of different formats; standards supported include OTH Gold, JUNIT, ADFORM, Link 11 and ADGESIT.

Llama Cheetah can be setup in many different configurations; Figure 3 shows one example of a Llama Cheetah configuration. Three Llama clients share picture, map, scene, and overlay data from a Llama Internet Server. Four Cheetah servers are connected in a serial topology.

4. Experimental Infrastructure

4.1 Infrastructure Components

The experimental environment consisted of the following components:

- Situational awareness application running on a computer with screen, keyboard and mouse:
    - ELEXSA Enhanced Llama for one group; and
    - Standard Llama for the other group;
- An operational scenario that exercises the capabilities of ELEXSA;
- Simulation environment that enables scenario entities to be modelled;
- Navigation tool for steering the simulated helicopter; and
- Range calculator for manually calculating radar detection ranges based on emitter data displayed by Standard Llama.

Both instantiations of Llama were instrumented to record performance data.

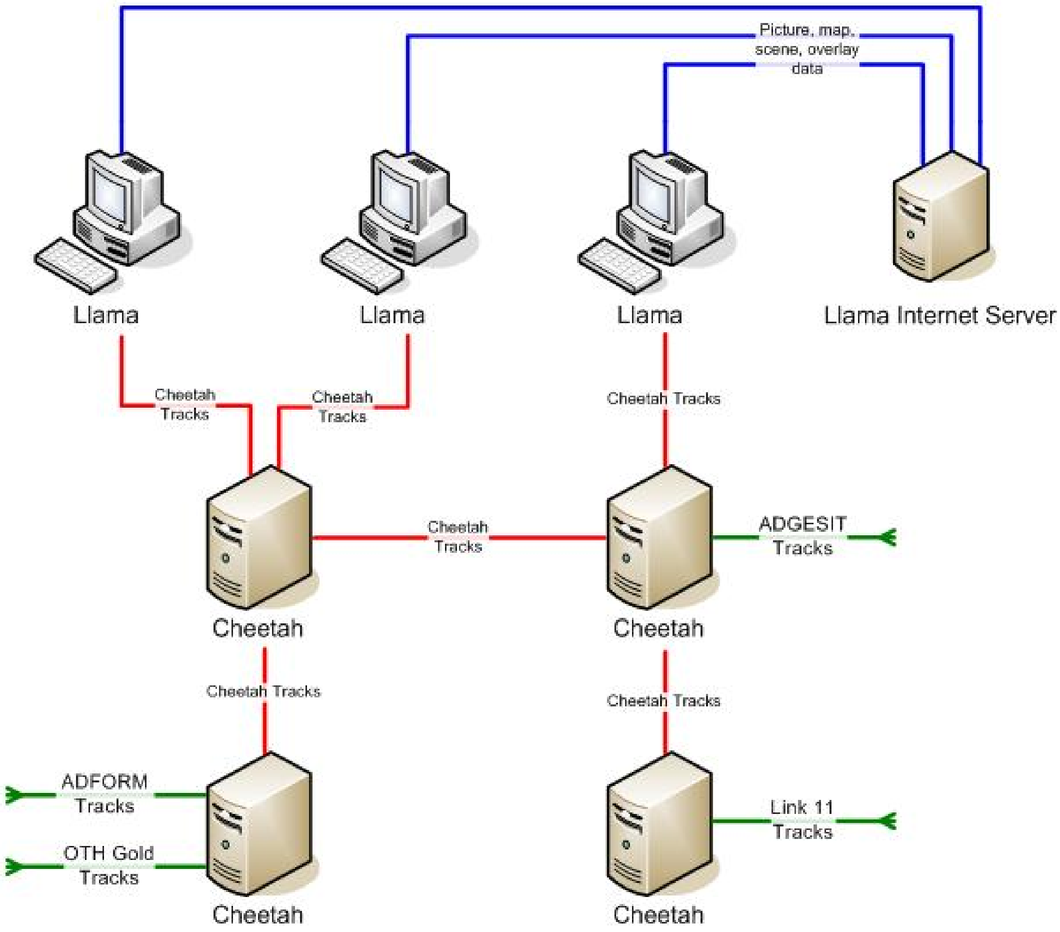

Figure 3. Example Llama/Cheetah Network Layout.

4.2 FLEWSE

DSTO has developed a synthetic environment known as the Force Level Electronic Warfare Synthetic Environment (FLEWSE) to help in the development of concepts of operation for EW systems.

A schematic of the FLEWSE architecture is provided in Figure 4 and shows the main system components. For the purposes of the experiment described in this document, these are the Scenario Toolkit and Generation Environment (STAGE) and Combined Sensor Modelling Infrastructure (CSMI).

Components are connected via a High Level Architecture (HLA) compliant framework. A benefit of HLA is that it provides an ability to connect other external HLA compliant models into FLEWSE .

As well as modelling the motions of entities such as aircraft, ships and unmanned aerial vehicles (UAVs), FLEWSE's key capability is modelling the electromagnetic interactions between these entities.

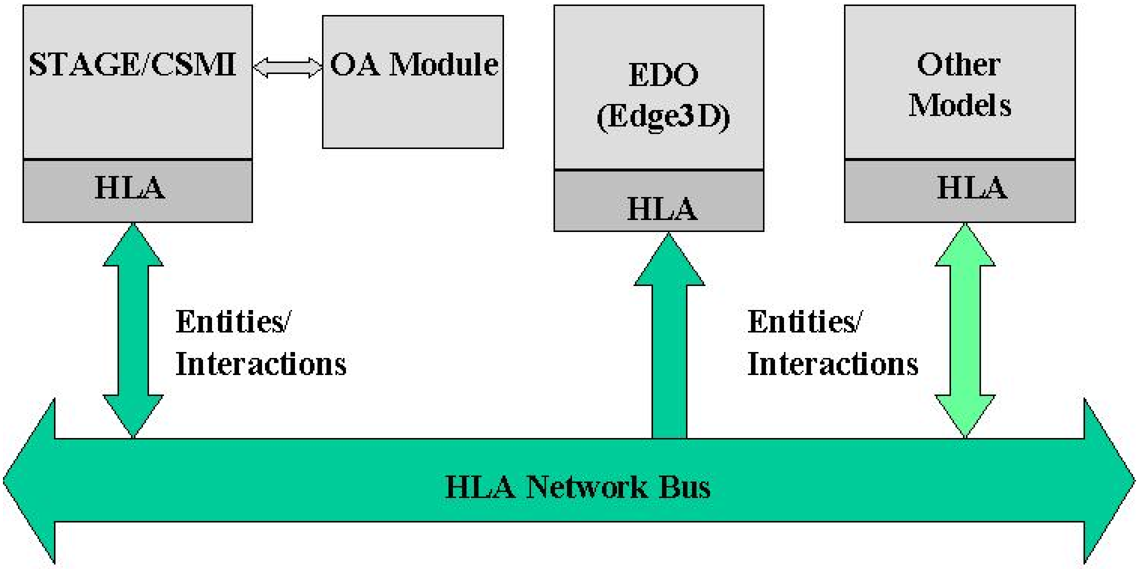

Figure 4. The FLEWSE Architecture.

4.3 Experimental Developments

To connect FLEWSE, Cheetah and ELEXSA a software module was developed, the HLA Bridge. In addition, software components for ELEXSA OA, ELEXSA SA and enabling operator control of the helicopter within FLEWSE were also developed.

The HLA Bridge subscribes to ELINT data provided by FLEWSE. The HLA Bridge formats the ELINT data and provides it to ELEXSA OA. The HLA Bridge also obtains own-ship and friendly force tracks from FLEWSE, translates to the appropriate format and sends to a Cheetah server.

The ELEXSA OA software receives ELINT data from the HLA Bridge and exploits ELEXSA databases to yield the OA. This OA is sent to Cheetah and onward to the situation monitoring tool, Llama. A schematic of this set-up is shown in Figure 5.

The ELEXSA Enhanced Llama software was modified to incorporate the computation and display of enriched information provide by ELEXSA SA. The changes include:

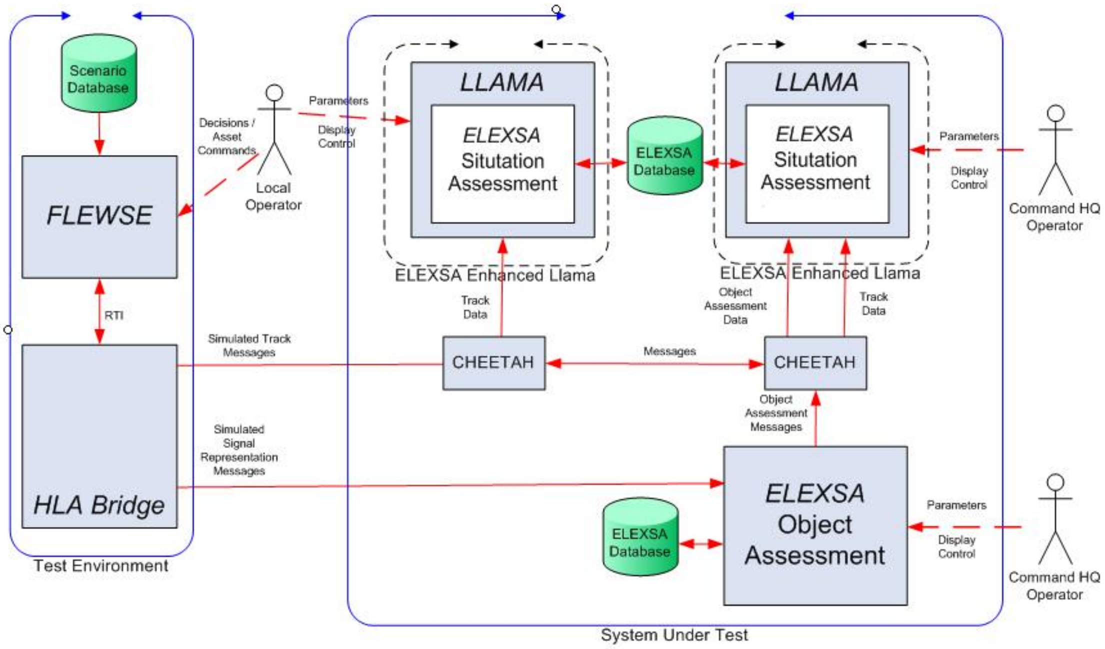

Figure 5. Experimental Set-up.

- Calculate the detection range of each radar mode against own-ship radar cross section using propagation physics (it is assumed that the altitude of the helicopter does not change and terrain shielding is not taken into account).
- The detection range of hostile emitters is automatically displayed to the operator.
- Record the time own-ship is within detection range of hostiles. This is used to measure the performance of the operator.

Figure 6 shows a screenshot of the ELEXSA Enhanced Llama application while the human-in-the-loop scenario is running.

Figure 7 shows a screenshot of standard Llama application while the human-in-the-loop scenario is running. The Standard Llama environment does not automatically calculate and display detection range information. However, several graphical interfaces were developed to allow the operator to access the same information about detected entities as was embedded within ELEXSA Enhanced Llama. Using these interfaces the operator must first enter the emitter signature into the detection range calculator (shown in Figure 8) to obtain a value for the maximum detection range of the emitter. When the operator has a value for the detection range of the emitter, they may manually draw circles in the situation display. The detection range calculator is available only in the Standard Llama environment (as detection ranges are automatically calculated and displayed in the Enhanced Llama environment).

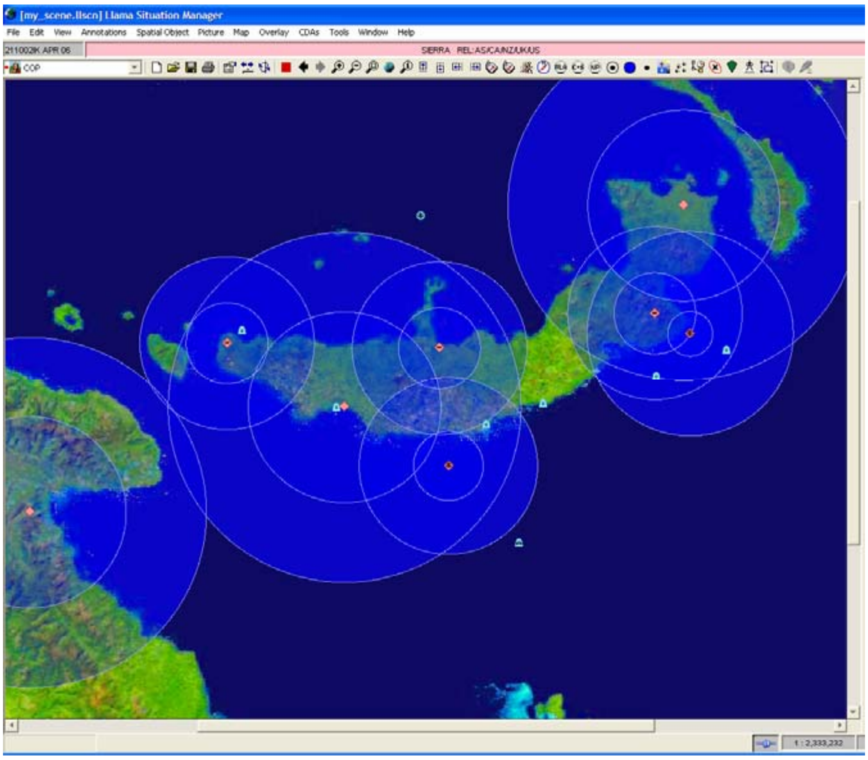

Figure 6. ELEXSA Enhanced Llama Visualisation.

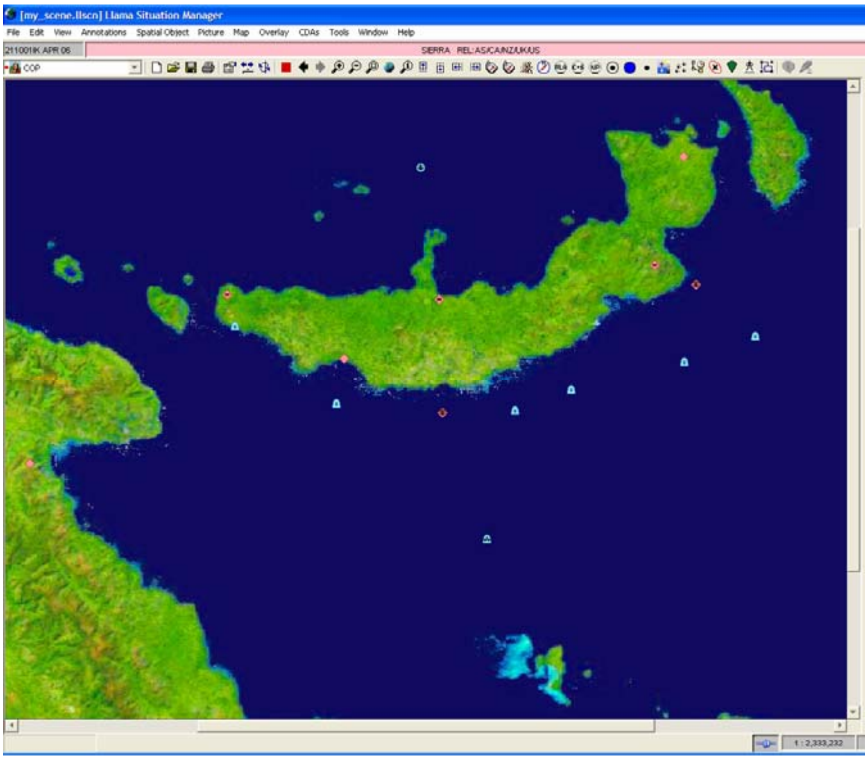

Figure 7. The Standard Llama Visualisation.

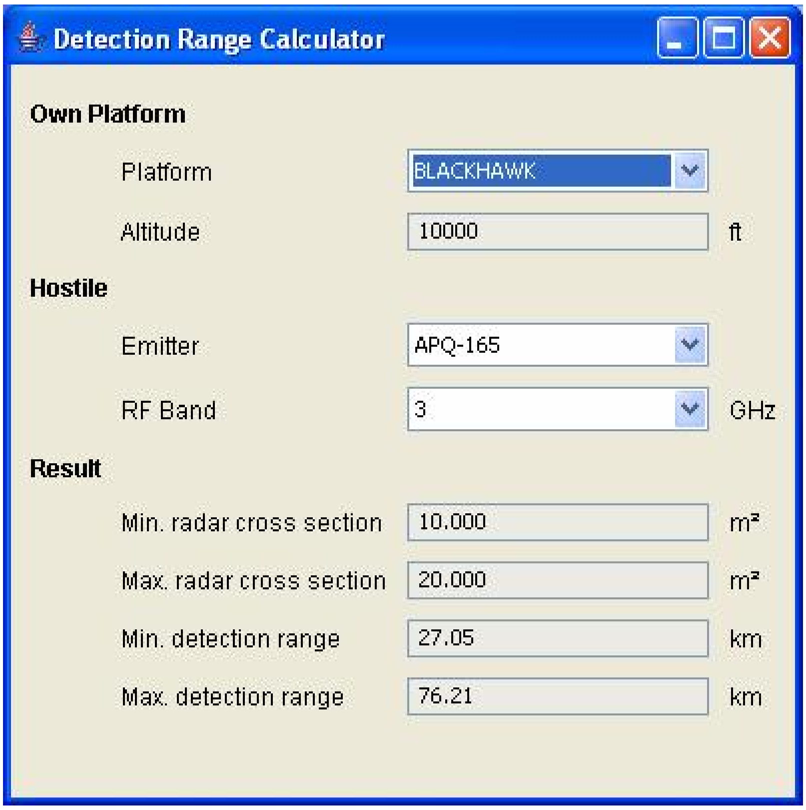

Figure 8. The Detection Range Calculator.

Software tools to allow control of the helicopter and awareness of helicopter fuel reserves were also developed:

- The Compass Controller to allow the Operator to control the heading of the helicopter. The operator cannot change the speed or altitude of the helicopter. A screenshot of the compass controller is shown in Figure 9.
- The fuel remaining indicator displays how minutes of fuel remain. It counts down from 15 minutes. A screenshot of the fuel remaining indicator is shown in Figure 10.

Both of these tools were available in both Llama environments.

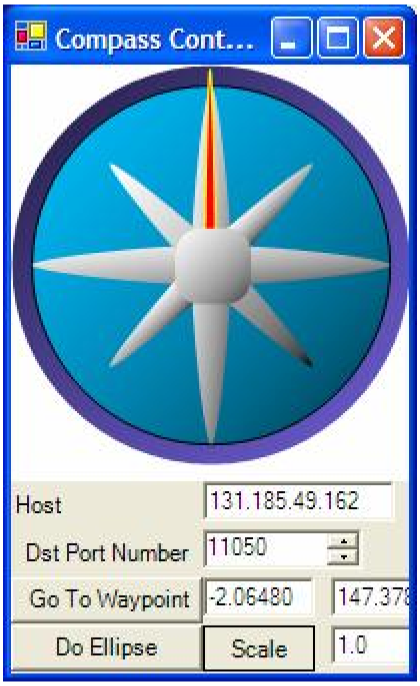

Figure 9. The Compass Tool.

Figure 10. The Fuel Remaining Indicator.

5. Methodology

5.1 Overview

The experiment measured the performance of the two groups of operators in achieving the same tactical goals within the same operational scenario, using the two different, but functionally equivalent situation assessment tools: Standard and Enhanced Llama-Cheetah.

Two groups of operators conducted the experiment; enhanced Llama operators and standard Llama operators.

1. Enhanced Llama operators were provided with an automatic visualisation for the detection range of hostile radars. When the EW signature was available, the enhanced Llama calculated the detection range using ELEXSA and displayed the range as a blue semi-transparent ring as shown above in Figure 6.
2. Standard Llama operators did not have the automatic visualisation of the detection range of hostile radars. Instead, they were required to enter the EW signature into the detection range calculator (Figure 8) and then use the drawing tools available within Llama to draw the detection ranges, as shown above in Figure 7.

5.2 Operational Scenario

The experiment was conducted using a simulated tactical environment. Each operator was required to navigate a Black Hawk helicopter around an archipelago nation that had recently been over-run by a hostile force and successfully land the helicopter on its host ship.

The hostile force had installed several Big Bird radar surveillance systems integrated with several Snowdrift missile systems and many MANPADS capable combat teams to protect itself from attack. The hostile force also has two naval vessels: a patrol boat with Don-2 radar and one Sovremenny class vessel. Both vessels patrol near the coast.

Forward of the helicopter was a number of Unmanned Air Vehicles (UAVs) equipped with ELINT sensors. Detections from these sensors were transmitted to the helicopter for interpretation and visualisation on its situational awareness display.

At the beginning of the scenario, the helicopter had almost completed a circuit of the archipelago; there was one more island to cross to reach its host ship. There was approximately 15 minutes of fuel remaining onboard the helicopter, so to successfully complete the mission with the allotted amount of fuel; the operator was required to traverse the last island rather than circumnavigating it. The operator was aware of the hostile force and its capabilities.

The goal of the operator was to avoid detection by the radar systems, possible destruction by the MANPADS and land on the ship before running out of fuel. If the helicopter loitered in a region where it was vulnerable to detection by a radar for more than 30 seconds, for the purposes of this experiment, it was assumed that the radar system detected the helicopter and reported its location to a MANPADS in the vicinity with lethal consequences (i.e. P_{kill} = 100% if the helicopter was within the radar's detection range for more than 30 seconds). The simulation was played at faster than real time to enable a tractable experiment to be conducted within a reasonable amount of the participant's time.

5.3 Data Acquisition

During the experiment, the following information was recorded for each operator:

- The time taken for the helicopter to reach its host ship (if the mission was successful);
- The times when the helicopter was within the detection range of any of the hostile radars; and
- Any failure to reach the host ship due to either being shot down by a MANPAD or running out of fuel.

After each operator had completed their mission, they were asked a small number of questions to solicit their perceptions of:

- Their workload and stress level;
- The amount of time they felt vulnerable to detection;
- The utility of the tools

5.4 Analysis

Statistical hypothesis testing was used to determine whether the ELEXSA enhancements improved, degraded or had no impact on the operator's awareness of threats in their tactical environment. In statistical hypothesis testing, the question of interest is simplified into two competing hypotheses between which we have a choice; the null hypothesis, denoted H_0, and the alternative hypothesis, denoted H_1. The experiments are then carried out in an attempt to disprove the null hypothesis. The null hypothesis cannot be rejected unless the evidence against it is sufficiently strong. This is due to the fact that the null hypothesis relates to the statement being tested, whereas the alternative hypothesis relates to the statement to be accepted if the null is rejected. The final conclusion once the test has been carried out is always given in terms of the null hypothesis. We either 'reject H_0 in favour of H_1' or 'do not reject H_0'; we never conclude 'reject H_1', or even 'accept H_1'. If we conclude 'do not reject H_0', this does not necessarily mean that the null hypothesis is true, it only suggests that there is not sufficient evidence against H_0 in favour of H_1; rejecting the null hypothesis then, suggests that the alternative hypothesis may be true.

The significance level of a statistical hypothesis test is a fixed probability of wrongly rejecting the null hypothesis H_0, if it is in fact true. That is, the significance level is made as small as possible in order to protect the null hypothesis. We have chosen a significance level of 0.05 = 5%.

The critical value(s) for a hypothesis test is a threshold to which the value of the test statistic in a sample is compared to determine whether or not the null hypothesis is rejected.

The critical value for any hypothesis test depends on the significance level at which the test is carried out, and whether the test is one-sided or two-sided.

The three hypotheses developed to determine the effect of the ELEXSA enhancements on operator's threat awareness were:

- *Hypothesis 1*:
  H_1 = Use of Enhanced Llama-Cheetah results in better operator survivability than Standard Llama-Cheetah
  H_0 = Use of Enhanced Llama-Cheetah does not result in better survivability than standard Llama
  In order to test this hypothesis, the average number of operators safely landing the helicopter on the ship is tallied for both Standard Llama-Cheetah (B_finished) and Enhanced Llama-Cheetah (E_finished). If there is not sufficient evidence against H_0 in favour of H_1, the difference between the numbers of operators successfully completing the mission will not be statistically significant.
- *Hypothesis 2*:
  H_1 = Use of Enhanced Llama-Cheetah results in shorter mission durations than Standard Llama-Cheetah
  H_0 = Use of enhanced Llama-Cheetah does not result in shorter mission durations than Standard Llama-Cheetah
  In order to test this hypothesis, the average time taken by both groups of operators to safely land the helicopter on the ship is calculated for both Standard Llama-Cheetah (B_time_taken) and Enhanced Llama-Cheetah (E_time_taken). If there is not sufficient evidence against H_0 in favour of H_1, the difference between the average times taken to successfully complete the mission will not be statistically significant.
- *Hypothesis 3*:
  H_1 = Use of Enhanced Llama-Cheetah results in a reduction in the time the Helicopter is venerable to detection than Standard Llama-Cheetah
  H_0 = Use of Enhanced Llama-Cheetah does not results in a reduction in the time the Helicopter is venerable to detection than Standard Llama-Cheetah
  In order to test this hypothesis, the average time spent by both groups of operators helicopters within the detection ranges of hostile radars is calculated for both Standard Llama-Cheetah (B_seen) and Enhanced Llama-Cheetah (E_seen). If there is not sufficient evidence against H_0 in favour of H_1, the difference between the average times spent by operators within the detection ranges of hostile radars will not be statistically significant.

In addition to the statistical hypothesis testing, the operator's anecdotal perception of their own vulnerability was compared against the ground truth. The ground truth measurements were obtained from log files of the relative position of the helicopter and threat radars. The operator reports on their perception of their workload were also compared for the two Llama-Cheetah environments. Interview anecdotes were mapped into high, medium or low measures.

6. Conduct of the Experiment

6.1 Personnel

The following personnel assisted in the conduct of the experiment:

- Coordinators. Responsible for briefing operators and co-ordinating each scenario execution; and
- Operators. Responsible for executing the scenarios. Operators were randomly assigned from a pool of 16 into two experimental groups of 8 members each. Eight operators were chosen from both Thales Australia and DSTO. The chosen operators did not have detailed knowledge of Llama or ELEXSA and as such, they required some training in the use of Llama (outlined in Section 6.2). Most operators had some expertise with software and modelling and some had military expertise from previous work roles.

6.2 Training

Before their mission began, each operator was provided with training by a coordinator. During their training, each operator was given an induction which explained the experimental aims and the operational scenario. Operators were then provided with some training in the use of Llama-Cheetah. This part of the training consisted of two phases: a PowerPoint overview of the capabilities of Llama, and a hands-on period to gain practice in the tasks required.

All the operators were trained in:

- How to interpret icons on the screen;
- How to interrogate icons on the screen;
- How to measure fuel remaining;
- How to steer the helicopter;
- How to land the helicopter; and
- How to use zoom and pan buttons.

Operators using Standard Llama were also trained in:

- How to use the detection range calculator;
- How to find the distance between two clicked points; and
- How to overlay a circle with a desired radius on the screen.

After the training was completed, operators were given a representative Llama task to complete. Had an operator been unable to perform the required task, the training would have been repeated, however this did not occur.

6.3 Conduct of Serials

As the operator came "on duty", the experiment coordinators checked that they were ready and started the simulation. The operator clicked the time clock to start the session. The operator then responded to information presented by Llama until the mission was successfully completed or the 15 minute fuel limit was reached. At the end of the run, the coordinators interviewed the operator using a standard set of questions in order to obtain additional information regarding their experience. After each operator had completed their session, the experiment coordinator verified that the experimental infrastructure performed as expected, that the flight log file had been correctly written and archived, and that other records identifying the operator's start and end times had also been written. In all cases this process was successfully completed.

6.4 Experimental Serials

In all, 16 serials were completed, 8 for Standard Llama and 8 for ELEXSA Enhanced Llama.

7. Observations

7.1 Mission Completion and Vulnerability Data

The mission time and time vulnerable to detection for each operator is shown below. Table 1 shows the results for operators using Standard Llama. Table 2 shows the results for operators using ELEXSA Enhanced Llama. Mission durations of 900 s indicate that the operator ran out of fuel and crashed.

Table 1. Results for operators using Standard Llama. Snow drift, Don-2 and Big Bird were the threat radar systems used during the experiment.

Operator Number	Mission Duration (s)	Time Vulnerable to Radar Detection (s)				
		SNOW DRIFT	DON-2	BIG BIRD	BIG BIRD	Total
1	900.000	0	0	0	0	0
2	702.994	0	232.721	114.356	0	347.077
3	900.000	11.235	51.703	91.546	0	154.484
4	900.000	0	0	182.848	122.646	305.494
5	608.825	0	0	0	0	0
6	762.151	0	0	14.540	0	14.540
7	704.833	0	48.204	46.891	0	95.095
8	900.000	0	0	0	0	0

For operators using Standard Llama, the average time taken to reach the destination was 797.350 seconds and the standard deviation was 117.346 seconds.

Table 2. *Results for operators using ELEXSA Enhanced Llama. Snow drift, Don-2 and Big Bird were the threat radar systems used during the experiment.*

Operator Number	Mission Duration (s)	Time Vulnerable to Radar Detection (s)				
		SNOW DRIFT	DON-2	BIG BIRD	BIG BIRD	Total
1	572.704	0	0	0	0	0
2	546.179	0	0	0	0	0
3	543.275	0	0	0	0	0
4	557.047	0	0	0	0	0
5	535.083	0	0	0	0	0
6	564.426	0	0	0	0	0
7	557.107	0	0	0	0	0
8	572.751	0	0	0	0	0

For operators using ELEXSA Enhanced Llama, the average time taken to reach the destination was 556.072 seconds and the standard deviation was 13.778 seconds.

7.2 Interview Results

The interview records are included as Appendix 1. These data have been collated into Tables 3 and 4 below. Table 3 shows data for operators using standard Llama. Table 4 shows data for operators using ELEXSA Enhanced Llama.

In both tables the operators perception of their vulnerability to any radars (V = perceived to be vulnerable, U = undecided, N = perceived not to be vulnerable) is shown together with the experimental measured vulnerability (V = Vulnerable, N =

Not Vulnerable). In addition an assessment of the operator's perceived workload and stress level as high medium or low is shown.

Table 3. Interview results for operators using Standard Llama.

	Op 1	Op 2	Op 3	Op 4	Op 5	Op 6	Op 7	Op 8
Perceived to be Vulnerable	N	V	U	N	V	N	V	V
Measured to be Vulnerable	N	V	V	V	N	V	V	N
Workload and Stress Level	Low	High	Med	High	Med	Low	High	High

Table 4. Interview results for operators using ELEXSA Enhanced Llama.

	Op 1	Op 2	Op 3	Op 4	Op 5	Op 6	Op 7	Op 8
Perceived to be Vulnerable	N	N	N	N	N	N	N	N
Measured to be Vulnerable	N	N	N	N	N	N	N	N
Workload and Stress Level	Low	Low	Low	Low	Med	Low	Low	Low

8. Analysis

8.1 Analysis Techniques and Definitions

To test Hypothesis 1, the Fisher Exact Probability Test was used. This test is overviewed in Appendix 2 and is described in [1].

To test Hypotheses 2 and 3, the two sided t-test was used. This test is overviewed in Appendix 3 and is described in [1].

The definition of survivability used in this experiment is of completing the mission by landing on the host vessel. There are two sources of mission failure:

- Being shot down ; and
- Running out of fuel.

In the experimental scenario, being in the detection zone of any radar for more than 30 seconds was postulated as enough time for the helicopters position to be determined and disseminated to a MANPADS in the vicinity with a lethal outcome. Given that ELEXSA is about survivability against radar threats in a tactical mission, survivability in this experiment is measured as:

- Successfully landing the helicopter on the parent ship; and
- Not being within the detection range of a radar for more than 30 seconds.

8.2 Hypothesis 1

In the first hypothesis, the aim is to test whether any difference in the proportion of Standard Llama operators completing the assigned mission and the proportion of Enhanced Llama operators completing the assigned mission is statistically significant. The data presented in section 7 was used in a Fisher Exact Probability Test.

A 2x2 contingency table (as described in Appendix 2) used to express the relationship between the variables for the ELEXSA HIL Experiment's first hypothesis is shown in Table 5.

Table 5. The 2x2 contingency table representing the proportion of operators successfully completing the mission for both Standard and Enhanced Llama-Cheetah environments.

	Standard Llama	Enhanced Llama	Total
Completed	2	8	10
Not completed	4	0	4
Total	6	8	14

P_{cutoff} has been computed for this experiment to be 0.003.

By summing the probabilities of all other matrices with the same marginal totals and sample size which are less than or equal to the $P_{cuttoff}$, a two sided probability of 0.015 is obtained. Since this value is less than the significance level of 0.05, the proportion of operators successfully completing the assigned mission is statistically significant i.e. there is a statistically significant association between the type of Llama used by the operator and the operator successfully completing the mission. Thus the null hypothesis can be rejected and Hypothesis 1 (at 95% level) can be accepted.

Note that there were two operators who ran out of fuel but stayed outside detection ranges. These operators were very cautious. These 2 operators were excluded from the analysis based on the adopted definition of survivability and so are not included in Table 5. If these two operators are included in the analysis, since they failed to complete the mission, a two sided probability of 0.007 is obtained, which is less than the significance level of 0.05. Thus the null hypothesis can be rejected and Hypothesis 1 (at 95% level) can be accepted whether or not these operators are included in the analysis.

8.3 Hypothesis 2

For the second hypothesis, a *t*-test [2] was used. For both instantiations of Llama, the average time taken to return the helicopter to the ship was measured. All 16 operators were used in this analysis with those that ran out of fuel taking 15 minutes. The critical t value for 14 degrees of freedom and p = 0.05 (ie 95% confidence level) = 2.145. The calculated value of t was 5.78 and since it is larger than the critical value, the null hypothesis can be rejected and Hypothesis 2 (at 95% level) can be accepted.

8.4 Hypothesis 3

For the third hypothesis, a *t*-test was used. For both instantiations of Llama, the average time spent in "may be seen" regions of the threats was computed. All 16 operators were used in this analysis. The critical t value for 14 degrees of freedom and p = 0.05 (ie 95% confidence level) = 2.145. The calculated value of t was 2.28 and since it is larger than the critical value, the null hypothesis can be rejected and Hypothesis 3 (at 95% level) can be accepted.

8.5 Analysis of Interviews

Consideration of the results presented in Tables 3 and 4 allows the following assessments.

(1) The perceptions of operators using ELEXSA Enhanced Llama about their vulnerability to radar detection were accurate.
(2) The perceptions of operators using Standard Llama about the vulnerability to radar detection was not reliable with only 3 operators perceptions matching measured vulnerability. 3 operators thought they were not detected when they were and two operators thought they were detected when they were not.
(3) The median reported work load and stress level of operators using ELEXSA Enhanced Llama was ”low” whereas for those using Standard Llama was “high”.

8.6 Sample Size

As mentioned in Section 6.1, two groups of operators were used in the conduct of the experiment. Each group of operators comprised 8 members.

The data presented in Section 7 included computations of mean and standard deviation. For operators using Standard Llama, the average time taken to reach the destination was 797.350 seconds and the standard deviation was 117.346 seconds. For operators using ELEXSA Enhanced Llama, the average time taken to reach the destination was 556.072 seconds and the standard deviation was 13.778 seconds. There is no overlap between the ranges of the standard deviations of these two sets of observations and so this suggests that the sample is large enough to reduce the effects of biases caused by operator competence levels for this experiment. Analysis immediately above shows that the results were significant at the 95% confidence level, indicating that the sample size is adequate.

Had additional experimental runs been undertaken it seems reasonable to expect that the result would be to reduce the standard deviation of the observations, particularly of the operators using Standard Llama. As additional experimental runs would incur additional costs and the sample size of two sets of 8 operators is adequate, it was decided not to undertake additional experimental runs.

9. Conclusions

This document has described the results of an experiment undertaken under an Interactive Project Agreement between DSTO and Thales Australia.

The experiment measured the performance of two groups of operators in achieving the same tactical goals in the same scenario using two different but functionally equivalent tool sets based on the Situational Awareness application Llama. In ELEXSA Enhanced Llama, information about detection ranges is always computed and displayed. In Standard Llama, operators may choose to compute and display this information.

The experiment was conducted using a simulated tactical environment. Each operator was required to navigate a helicopter through a hostile environment containing enemy radars integrated with MANPADS to land the helicopter on a host ship. The experiment recorded the times associated with the execution of the helicopter's mission, including times when the helicopter was within the detection range of the enemy radars, and the time of landing on the host vessel. The experiment also recorded any failure to reach the host ship due to either being shot down by a MANPADS or running out of fuel. Measurements were analysed to determine whether the ELEXSA enhancements improved, degraded or made no impact on operator situational awareness of threats in the tactical environment. The analysis consisted of three statistical hypothesis tests and assessment of anecdotal reports of the operator's experience.

Hypothesis test analyses, at 95% confidence level, showed that ELEXSA enhanced Llama: (1) increases operator survivability (2) shortens mission duration, and (3) reduces the time helicopter vulnerable to detection, compared to Standard Llama.

Analysis of interview results showed that operators using ELEXSA Enhanced Llama had lower workload and stress levels and more accurate perceptions of their vulnerability to radar detection than operators using Standard Llama.

10. References

[1] Agresti, A. (1990) *Categorical data analysis*. New York: Wiley.

[2] Student's t-test. (2006, August 9). In Wikipedia, The Free Encyclopaedia. Retrieved from http://en.wikipedia.org/w/index.php?title=Student%27s_t-test&oldid=68626963.

Appendix A: Operator Questionnaire

Answers to Questions for Standard Lama Operator 1

Do you think you were vulnerable to detection by any radars?
No. With the software, I can avoid radars. I could have taken a risk and attempted to navigate through the small gap. I decided it was safer to fly around, but ran out of fuel.

Did you feel that you had enough information about the detected radars?
Yes.

Did you feel you had enough time to react to new radar detections?
Yes.

Is there additional information that could have made your job easier?
The detection range circle moves when the ships move.

Do you feel the tools were useful and useable?
Yes.

What could be changed to improved useability?
The detection range circle moves when the ships move.

Summary: Operator 1 didn't get detected. Operator 1 didn't reach destination.

Answers to Questions for Standard Lama Operator 2

Do you think you were vulnerable to detection by any radars?
Yes. I wondered into the detection range at the start. Helicopter was moving too fast.

Did you feel that you had enough information about the detected radars?
Using manual checkup. Yes.

Did you feel you had enough time to react to new radar detections?
No. It is very difficult at the start. The scenario is not real time.

Is there additional information that could have made your job easier?
An audio alert when a new detection is discovered.

Do you feel the tools were useful and useable?
Useful, yes. But complicated to use. There a multiple tasks to do at once. Two operators (a navigator) would help.

What could be changed to improved useability?
Could be a automated; circles drawn automatically. A database lookup to calculate detection ranges.
Not to scale. Difficult to determine distance
A lookup table on a piece of paper would help. Lists likely threads and detection ranges.
Radius of circles displayed during circle created. (displayed when dragging).

Summary: Operator 2 was detected three times. Once by Big Bird, twice by DON-2. Reached destination in about 12:00 mins.

Answers to Questions for Standard Lama Operator 3

Do you think you were vulnerable to detection by any radars?
I was on the peripheral of some radars, on the borderline.

Did you feel that you had enough information about the detected radars?
Yes.

Did you feel you had enough time to react to new radar detections?
Yes. Some people can react faster than others. With more practice, my reaction would be faster.

Is there additional information that could have made your job easier?
I needed more practice.

Do you feel the tools were useful and useable?
Yes.

What could be changed to improved useability?
A touch screen with big square buttons.

Summary: Operator 3 was detected three times by Big Bird, DON-2 and snowdrift. Operator 3 didn't reach the destination.

Answers to Questions for Standard Lama Operator 4

Do you think you were vulnerable to detection by any radars?
No, of course.

Did you feel that you had enough information about the detected radars?
Yes

Did you feel you had enough time to react to new radar detections?
I was overloaded at the beginning. The task was cumbersome.

Is there additional information that could have made your job easier?
A way to identify hostiles that are the same. Hostiles that have the same emitter use the same colour, etc.

Do you feel the tools were useful and useable?
Useful yes. Maybe not useable.

What could be changed to improved useability?
Once hostiles detected the circles automatically appear. If the hostile moves, the circle moves with it.
Summary: Operator 4 was detected by Big Bird 1 and by Big Bird 2. Operator 4 didn't reach destination. Splash down 130km WSW of ship.

Answers to Questions for Standard Lama Operator 5

Do you think you were vulnerable to detection by any radars?
Yes, by one of the moving ships. It looked like they may cross.

Did you feel that you had enough information about the detected radars?
Yes

Did you feel you had enough time to react to new radar detections?
Probably.

Is there additional information that could have made your job easier?
No.

Do you feel the tools were useful and useable?
Yes.

What could be changed to improved useability?
I would rather hit 'enter' than 'apply' when adjusting circles radius.
Circles should follow platform movements. When you have lots to do, moving circles is cumbersome.
Calculated and Llama should be integrated.

Summary: Operator 5 didn't get detected and arrived at the destination in 10:15 minutes.

Answers to Questions for Standard Lama Operator 6

Do you think you were vulnerable to detection by any radars?
No. I had a clear picture. Only limitation was my own mistake at the beginning.

Did you feel that you had enough information about the detected radars?
Yes. The challenge is just using it correctly.

Did you feel you had enough time to react to new radar detections?
Yes. It is important to prioritise your time.

Is there additional information that could have made your job easier?
Circles created around hostiles automatically. Provide a warning rather than letting you wonder into detection.

Do you feel the tools were useful and useable?
Yes.

What could be changed to improved useability?
The interface is cluttered. Buttons and button position should be simplified.

Summary: Operator 6 was detected by Big Bird 2 and reached destination in approx. 13:15 mins.

Answers to Questions for Standard Lama Operator 7

Do you think you were vulnerable to detection by any radars?

Yes, based on the provided range calculation.

Did you feel that you had enough information about the detected radars?
How much do you need to know? How accurate is the intel?

Did you feel you had enough time to react to new radar detections?
No, not at that speed. If the scenario was real time it would have been better.

Is there additional information that could have made your job easier?
As the system can ID the radar types, the circles should be created automatically. The circle should auto follow moving vessels.

Do you feel the tools were useful and useable?
Yes. Symbology needs improving.

What could be changed to improved useability?
Someway of alerting the user of mobile hostiles.

Summary: Operator 7 was detected by Big Bird 2 and DON-2 twice and reached destination in approx. 11:50 mins.

Answers to Questions for Standard Lama Operator 8

Do you think you were vulnerable to detection by any radars?
Yes, one of the frigates. I was very close.

Did you feel that you had enough information about the detected radars?
Yes

Did you feel you had enough time to react to new radar detections?
No. If I had more time I would have taken a different route.

Is there additional information that could have made your job easier?
A scale on the map. Some indication of the detection range of UAVs.

Do you feel the tools were useful and useable?
Yes.

What could be changed to improved useability?
Double click to zoom out. Drag box should zoom in (currently it selects targets within box).

Summary: Operator 8 was not detected by any radars. Operator 8 failed to reach the destination.

Answers to Questions for ELEXSA Enhanced Lama Operator 1

Do you think you were vulnerable to detection by any radars?
No. If the circles are correct.

Did you feel that you had enough information about the detected radars?
Funny question. I think the information is correct. If I get 'pinged' by a hostile, I want to know what to do.

Did you feel you had enough time to react to new radar detections?
Yes.

Is there additional information that could have made your job easier?
No.

Do you feel the tools were useful and useable?
Yes.

What could be changed to improved useability?
Ability to return to the previous zoom level.
Two views of the world; A zoomed in view and a 'big picture' view.

Summary: Operator 1 didn't get detected. Reached destination in about 8:30 mins.

Answers to Questions for ELEXSA Enhanced Lama Operator 2

Do you think you were vulnerable to detection by any radars?
No. Not according to the information provided.

Did you feel that you had enough information about the detected radars?
Yes. I thought 'how reliable is the information?'

Did you feel you had enough time to react to new radar detections?
Yes.

Is there additional information that could have made your job easier?
No. I was worried something (a radar detection) would pop-up.

Do you feel the tools were useful and useable?
Yes.

What could be changed to improved useability?
The circles are blue. Blue indicates friendly. Perhaps should be red, but that might obscure the icon.

Summary: Operator 2 didn't get detected and reached destination in approx 9:00 mins.

Answers to Questions for ELEXSA Enhanced Lama Operator 3

Do you think you were vulnerable to detection by any radars?
No. Based on the information provided.

Did you feel that you had enough information about the detected radars?
Yes. There is never enough information. Enough information to determine a safe route.

Did you feel you had enough time to react to new radar detections?
Yes.

Is there additional information that could have made your job easier?
If the detection occurred earlier. I can foresee a situation where you could be trapped in a location by hostile radars.

Do you feel the tools were useful and useable?
Yes.

What could be changed to improved useability?
Mouse control of helicopter instead of compass.
Infinitely scroll with scroll bars rather than using the pan button.

Summary: Operator 3 wasn't detected and reached destination in about 9:00 mins.

Answers to Questions for ELEXSA Enhanced Lama Operator 4

Do you think you were vulnerable to detection by any radars?
No.

Did you feel that you had enough information about the detected radars?
Yes.

Did you feel you had enough time to react to new radar detections?
Yes. The detections were early enough.

Is there additional information that could have made your job easier?
No. I wanted to stay away from SAM sites. If I was going to fall into a detection range, I'd prefer it to be a RADAR site.

Do you feel the tools were useful and useable?
Yes.

What could be changed to improved useability?
Not really. It is a nice setup.

Summary: Operator 4 didn't get detected and reached destination in approx 9:30 mins.

Answers to Questions for ELEXSA Enhanced Lama Operator 5

Do you think you were vulnerable to detection by any radars?
Might have come close. No. I am relying on the information being accurate.

Did you feel that you had enough information about the detected radars?
Yes.

Did you feel you had enough time to react to new radar detections?
Yes. It was tight with the moving ships.

Is there additional information that could have made your job easier?
Yes.
Heading of hostile ships.
'Snail trail' or history of ships movement.
Weapon systems of the hostiles. If there was full coverage, and I was forced to enter a detection range, I'd want to know the weapon capabilities of the hostiles so I can make an informed decision where to fly with the lowest probability of being shot down.

Do you feel the tools were useful and useable?
Yes.

What could be changed to improved useability?
Zooming and panning is clunky.
Labels on hostile sites to identify the emitter.
A communications overlay.
Terrain information.

Summary: Operator 5 didn't get detected and reached destination in approx 9:00 mins.

Answers to Questions for ELEXSA Enhanced Lama Operator 6

Do you think you were vulnerable to detection by any radars?
No.

Did you feel that you had enough information about the detected radars?
Yes.

Did you feel you had enough time to react to new radar detections?
Yes

Is there additional information that could have made your job easier?
More UAVs. The UAV provide good feedback.

Do you feel the tools were useful and useable?
Yes.

What could be changed to improved useability?
No. It was good.

Summary: Operator 6 didn't get detected and reached destination in approx 9:30 mins.

Answers to Questions for ELEXSA Enhanced Lama Operator 7

Do you think you were vulnerable to detection by any radars?
No.

Did you feel that you had enough information about the detected radars?
Definitely.

Did you feel you had enough time to react to new radar detections?
Definitely.

Is there additional information that could have made your job easier?
No. I would like the helicopter to go faster.

Do you feel the tools were useful and useable?
Definitely.

What could be changed to improved useability?

No. Perhaps some weapons to take out the radars.

Summary: Operator 7 was not detected and reached destination in approx. 9:17 mins.

Answers to Questions for ELEXSA Enhanced Lama Operator 8

Do you think you were vulnerable to detection by any radars?
No.

Did you feel that you had enough information about the detected radars?
Yes.

Did you feel you had enough time to react to new radar detections?
Yes.

Is there additional information that could have made your job easier?
An arrow indicating the heading of the helicopter.

Do you feel the tools were useful and useable?
Yes.

What could be changed to improved useability?
No. Zoom and scroll is similar to other PC tools.

Summary: Operator 8 was not detected and reached destination in approx. 9:30 mins.

Appendix B: The Fisher Exact Probability Test

The Fisher Exact Probability Test is a statistical test used in the analysis of categorical data where the sample sizes are relatively small. Categorical data is defined as data which belongs to exactly one of a finite set of categories. The test is used when members of two independent groups can fall into one of two mutually exclusive categories. In the ELEXSA Human in the Loop Experiment, the two independent groups are the operators who used Standard Llama and those that used Enhanced Llama and the two mutually exclusive categories, in the case of the first hypothesis, are completing and not completing the assigned mission. The Fisher test is used to determine whether the proportion of the members from the independent groups falling into each category differs based on the group.

In the Fisher test, as there are two independent groups and two categories, a 2x2 contingency table is used. In statistics, contingency tables are used to record and analyse the relationship between two or more categorical variables. A 2x2 contingency table used to express the relationship between the variables is shown in Table B1 where the values of the cells are represented by the letters *a, b, c* and *d*, the totals across rows and columns are referred to as *marginal totals*, and the *grand total* is represent by *n*.

Table B1. A 2x2 contingency table.

	Standard Llama	Enhanced Llama	Total
Completed	a	b	a + b
Not completed	c	d	c + d
Total	a + c	b + d	n

If there were no systematic association between the Standard Llama and Enhanced Llama groups within the population, the probability of observing any particular set of frequencies a, b, c, d (i.e. any particular arrangement of the data) in a 2x2 contingency table, given fixed values for the marginal totals a+b, c+d and sample size n, would be given by

$$p = \frac{\binom{a+b}{a}\binom{c+d}{c}}{\binom{n}{a+c}}$$

which reduces to

$$= \frac{(a+b)!(c+d)!(a+c)!(b+d)!}{n!\,a!\,b!\,c!\,d!}$$

This value is know as P_{cutoff}.

By summing the probabilities of all other matrices with the same marginal totals and sample size which are less than or equal to the $P_{cuttoff}$, a two sided probability is obtained. If this value is less than the significance level of 0.05, the proportion of operators successfully completing the assigned mission is statistically significant i.e. there is a statistically significant association between the type of Llama used by the operator and the operator successfully completing the mission. Thus the null hypothesis can be rejected and Hypothesis 1 (at 95% level) can be accepted.

In the case of Hypothesis One, the Fisher Exact Test is a better choice than the Chi-square test because in order to use the Chi Squared test, the raw observed frequencies cannot be too small and further, because some of the mathematical formulas used in chi square use division, no cell in the table can have an observed raw frequency of 0. Also the Chi squared test gives only an approximate solution, whereas the Fisher test returns exact one tailed and two tailed p-values.

Appendix C: The *t*-test

The *t*-test is the most commonly used method to assess whether the means of two groups are statistically different from each other. For example, the *t*-test can be used to test for a difference in test scores between a group of patients who were given a drug and a control group who received a placebo. Theoretically, the t-test can be used even if the sample sizes are very small (e.g., as small as 10), as long as the variables are normally distributed within each group and the variation of scores in the two groups is not reliably different. In simple terms, the t-test compares the actual difference between the means in relation to the variation in the data which is expressed as the standard deviation of the difference between the two means.

T Test Procedure

For the two samples, EL and SL, of sizes of N_{EL} and N_{SL} respectively, calculate

The mean μ_{EL} and sum of squared deviates $\mathbf{SS_{EL}}$ of EL

The mean μ_{BL} and sum of squared deviates $\mathbf{SS_{SL}}$ of SL

where

$$\mathbf{SS} = \sum x_i^2 - \frac{(\sum x_i)^2}{N}$$

Estimate the variance of the source population as:

$$\{\mathbf{s}_p^2\} = \frac{\mathbf{SS}_{EL} + \mathbf{SS}_{SL}}{(N_{EL} - 1) + (N_{SL} - 1)}$$

Estimate the standard deviation of the sampling distribution of sample-mean differences (the "standard error" of $\mu_{EL} - \mu_{SL}$) as

$$\text{est.}\,\sigma_{\mu - \mu} = \sqrt{\frac{s_p^2}{N_{EL}} + \frac{s_p^2}{N_{SL}}}$$

Calculate **t** as

$$t = \frac{\mu_{EL} - \mu_{SL}}{est.\sigma_{\mu-\mu}}$$

Once this value is calculated, it can be used in a look up table of significance to test whether the ratio is large enough to say that the difference between the groups is not likely to be a chance finding. That is, if a comparison between the calculated value of t to the critical values of t is performed and if the calculated value of t exceeds the tabulated value, the means are significantly different. The critical value for a hypothesis test is a threshold to which the value of the test statistic in a sample is compared to determine whether or not the null hypothesis is rejected. The critical value for any hypothesis test depends on the significance level at which the test is carried out, and whether the test is one-sided or two-sided and on the degrees of freedom. The level of significance is set at 0.5 (which means that 5 times out of 100, a statistically significant difference between the means even if there was none would be found) and the degrees of freedom = $N_{EL} + N_{SL} - 2$. The critical values are calculated from the t-distribution which has the probability density function:

$$f(t) = \frac{\Gamma((\nu+1)/2)}{\sqrt{\nu\pi}\,\Gamma(\nu/2)}(1+t^2/\nu)^{-(\nu+1)/2}$$

with ν equal to $n - 1$. The parameter ν is the number of degrees of freedom. The distribution depends on ν, but not μ or σ.

For example, for a sample set of 12 and a sensitivity of 5%, the critical values will be ±2.0.

An Assessment of ELINT Exploitation for Situational Awareness Visualisations on Operator Situational Awareness

Keith Mason, Jeff Sturm, Craig Keogh and Catherine Howard

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16. DELIBERATE ANNOUNCEMENT

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Situational awareness
Radar detection
Mission simulation

19. ABSTRACT
An Interactive Project Agreement (IPA) between Electronic Warfare and Radar Division of the Defence Science Technology Organisation and Thales Australia (formerly ADI Limited) has an initial aim to evaluate DSTO innovations flowing from its ELINT Exploitation for Situational Awareness (ELEXSA) task within Thales Australia's operational situational awareness tool Llama-Cheetah. This document outlines the human in the loop experiment undertaken to determine whether the visual enhancements provided by ELEXSA computational components increased operator situational awareness, thereby improving their ability to achieve tactical goals. Analysis of three hypotheses showed that ELEXSA Enhanced Llama: (1) increases operator survivability; (2) shortens mission duration; and (3) reduces the time helicopter spends vulnerable to detection, compared to Standard Llama. Analysis of anecdotal reports showed that operators using ELEXSA Enhanced Llama had lower workload and stress levels and more accurate perceptions of their vulnerability to radar detection than operators using Standard Llama.

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